

# New Ideas for long baseline experiments

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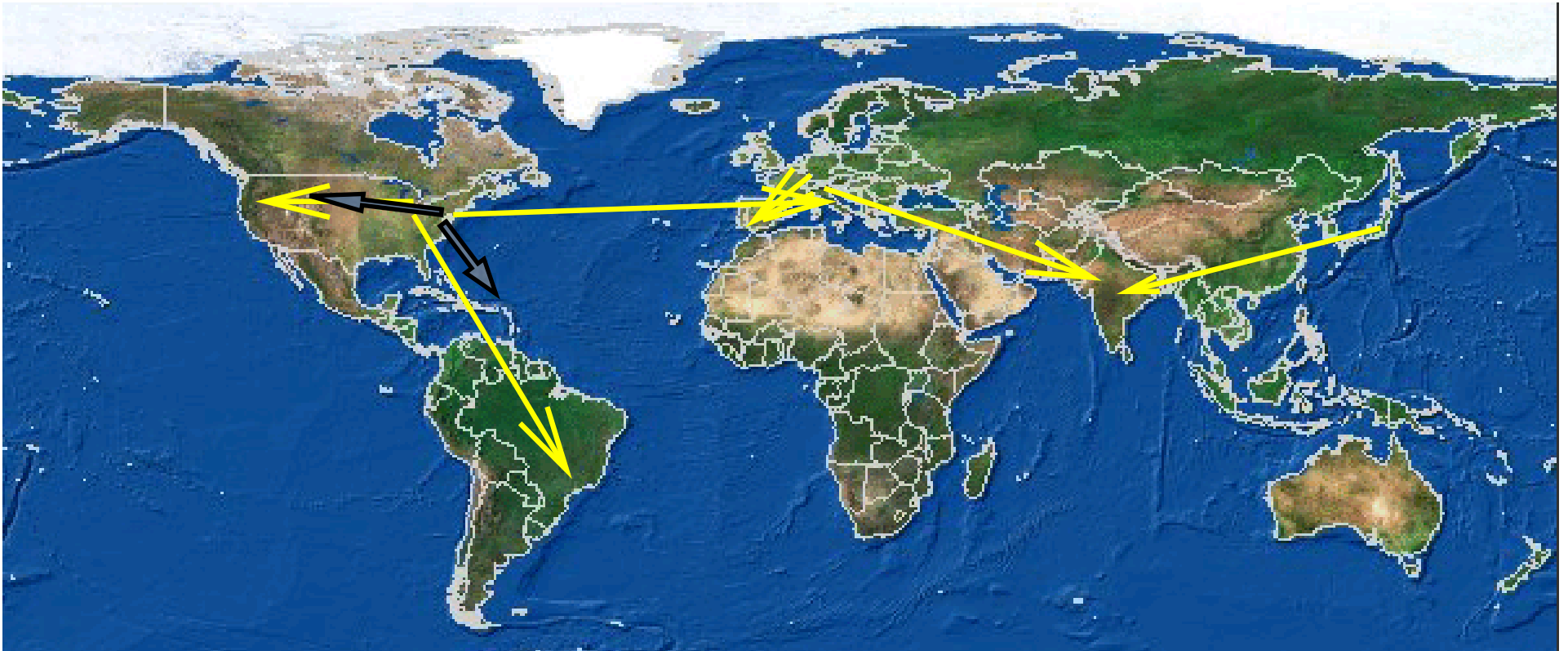
Brookhaven National Laboratory

HQL2004, San Juan, June 5 2004

# Agenda

- Why LBL nu exp. ? Physics issues and my interests.
- Rules of thumb for experimentalists.
- Technical issues for possible baselines and detectors.
- Event rates, backgrounds, measurement uncertainties, experimental strategies.

# Many Ideas ?



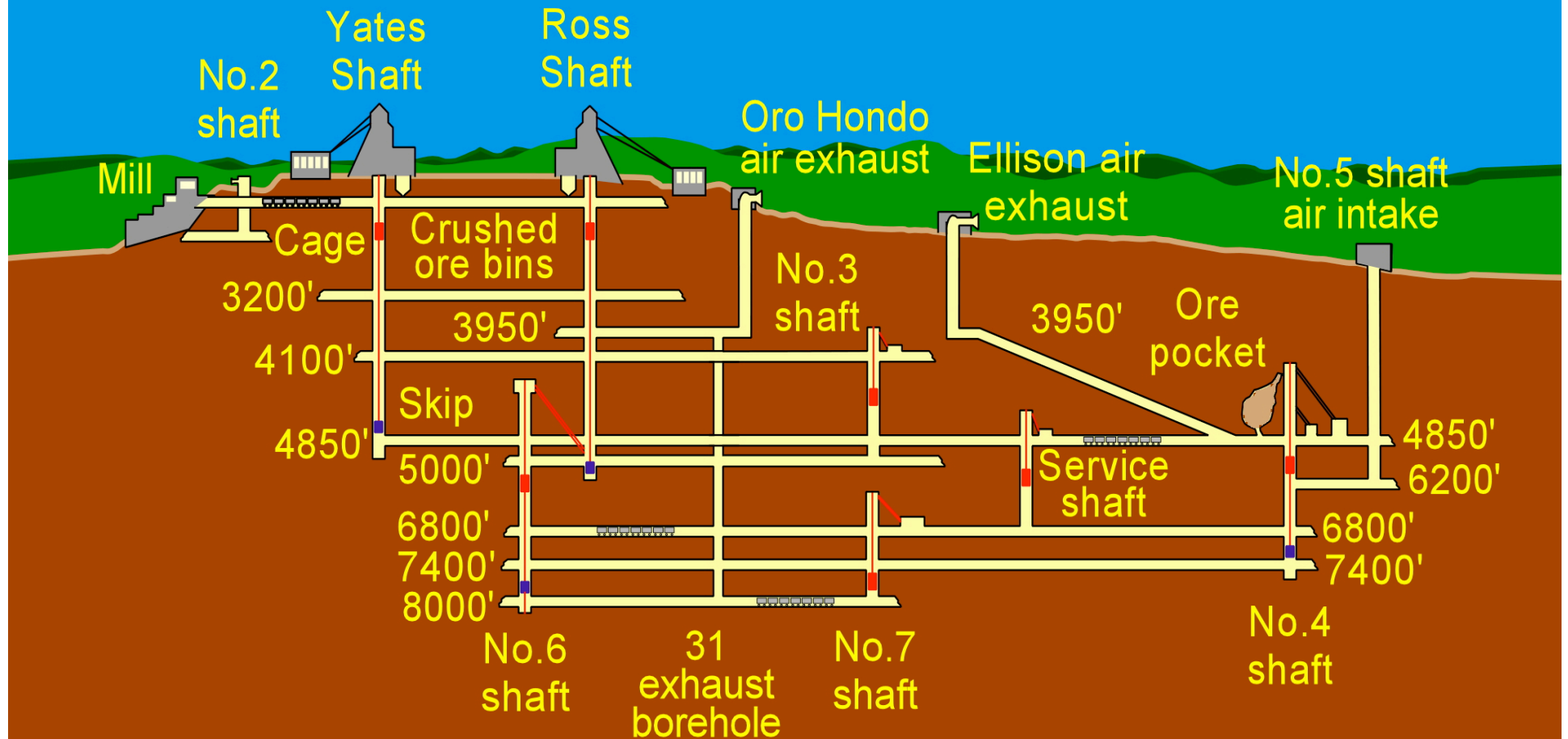
# Practical issues

- Need large detector. 100 kT to 500 kT.
- Need high energy accelerator Lab. FNAL, BNL, CERN, JPARC.
- Major upgrade to existing or completely new proton source needed.
- Must consider new ideas in US towards Deep National Underground Lab. (DUSEL)

# Aside on DUSEL (Deep Underground Science and Engineering Lab.)

- Since 1965, R.Davis experiment in Homestake Mine. Opportunity for a major facility at HS evident when mine closed in 2000. Proposal to NSF. Drama: water-in-mine.
- NSF started new process in March 2004 for DUSEL.
- Solicitation I: from entire scientific community for science. Modules: Deep (DM, solar nu, supernova), Large (nucleon decay, Long Baseline), Geo (physics, Engineering), Bio (exo-biology), National security. Date: due in Sep ?
- Solicitation II: Site specific proposals. Homestake (SD), Henderson (CO), Icicle Cr.(WA), San Jacinto (CA), VA. Must address all physics from Sol I. Due Oct. ?

# General Homestake Mine Development



# Big picture physics issues for neutrinos

- Precision measurements

$$\Delta m_{21}^2, \sin^2 2\theta_{12}, \Delta m_{32}^2, \sin^2 2\theta_{23}$$

- Implications of 3-generation mixing.

$$\nu_\mu \rightarrow \nu_e, \sin^2 2\theta_{13}, \delta_{CP}$$

- New physics: deviations from  $\sin^2 \frac{\Delta m^2 L}{4E}$ ,  
new interactions, new symmetries. Sterile  
neutrinos: (LSND-miniboone exp.)

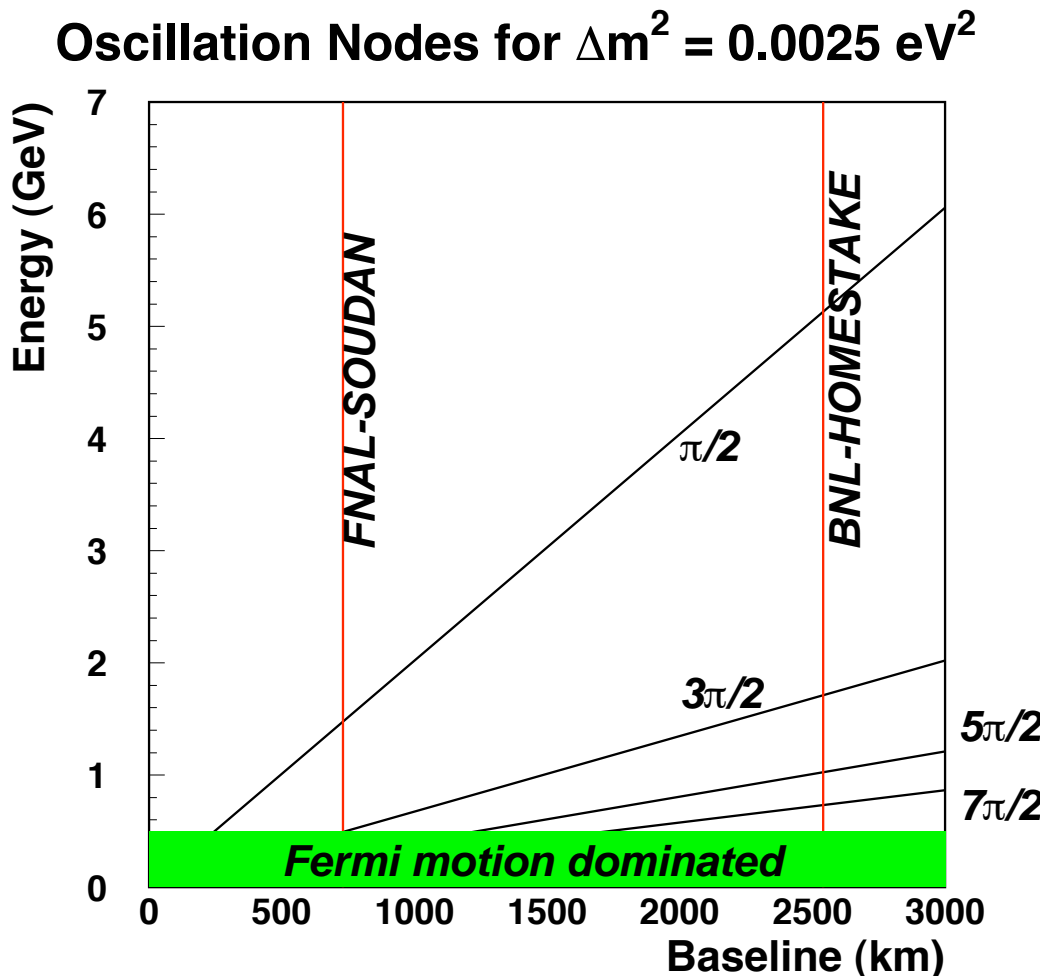
# My biases

- New detector facility (100-500kT) must address broad range of physics: Accelerator Neutrinos, Nucleon decay, Astrophysical Neutrinos.
- New detector most likely located deep.
- For neutrino oscillations must address the most difficult problem for reasonable range of parameters: CP violation.
- Exciting opportunity for younger people to make their mark.
- Does this make sense from physics point of view ?

# Distance and energy scale for long baseline neutrino experiment.

$$P(\nu_a \rightarrow \nu_a) = 1 - \sin^2 2\theta \sin^2 \frac{1.27(\Delta m^2 / \text{eV}^2)(L / \text{km})}{(E / \text{GeV})}$$

Oscillation nodes at  $\pi/2, 3\pi/2, 5\pi/2, \dots (\pi/2)$ :



- First node: 494 km
- Multiple nodes for precision exp.
- Cross section and fermi motion limits resolution at low energies for muon neutrino events.
- Need muon neutrino beam 0.5-6 GeV and 2000 km.

# $\nu_\mu \rightarrow \nu_e$ with matter effect

Approximate formula (Lindener, Huber et al.)

$$\begin{aligned}
 P(\nu_\mu \rightarrow \nu_e) \approx & \sin^2 \theta_{23} \frac{\sin^2 2\theta_{13}}{(\hat{A} - 1)^2} \sin^2((\hat{A} - 1)\Delta) \\
 & + \alpha \frac{8J_{CP}}{\hat{A}(1 - \hat{A})} \sin(\Delta) \sin(\hat{A}\Delta) \sin((1 - \hat{A})\Delta) \\
 & + \alpha \frac{8I_{CP}}{\hat{A}(1 - \hat{A})} \sin(\Delta) \cos(\hat{A}\Delta) \sin((1 - \hat{A})\Delta) \\
 & + \alpha^2 \frac{\cos^2 \theta_{23} \sin^2 2\theta_{12}}{\hat{A}^2} \sin^2(\hat{A}\Delta)
 \end{aligned}$$

$$J_{CP} = 1/8 \sin \delta_{CP} \cos \theta_{13} \sin 2\theta_{12} \sin 2\theta_{13} \sin 2\theta_{23}$$

$$I_{CP} = 1/8 \cos \delta_{CP} \cos \theta_{13} \sin 2\theta_{12} \sin 2\theta_{13} \sin 2\theta_{23}$$

$$\alpha = \Delta m_{21}^2 / \Delta m_{31}^2, \quad \Delta = \Delta m_{31}^2 L / 4E$$

$$\hat{A} = 2VE / \Delta m_{31}^2 \approx (E_\nu / \text{GeV}) / 11 \quad \text{For earth's crust}$$

# Electron neutrino appearance physics parameter extraction

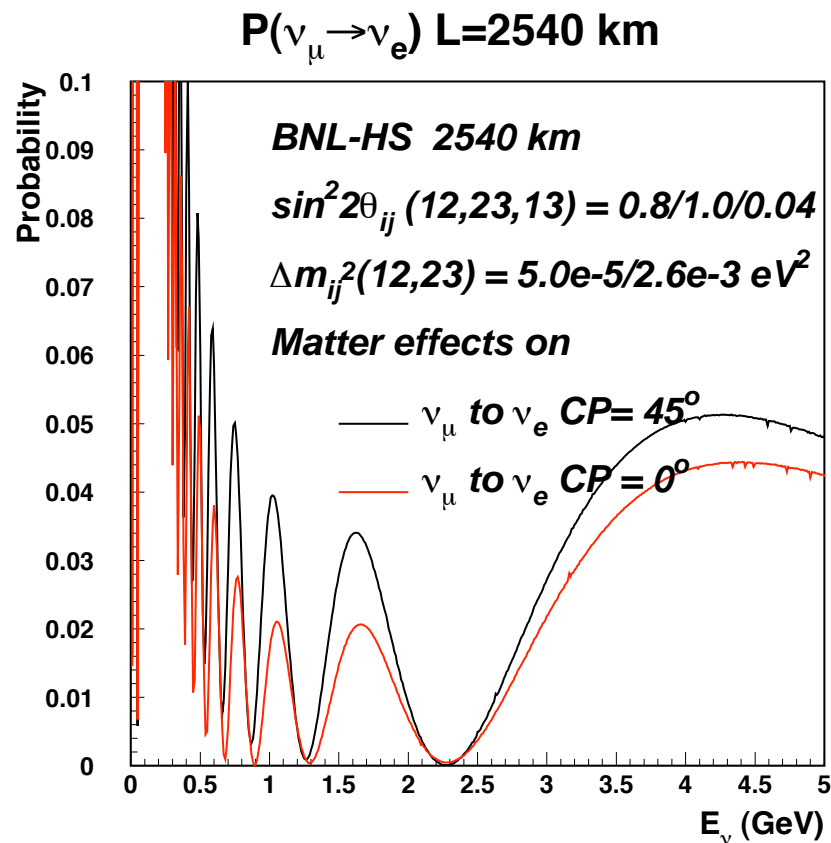
Assume  $L > 2000\text{km}$ , wide band beam

$\Delta m_{32}^2$ ,  $\Delta m_{21}^2$ ,  $\theta_{12}$  well known.

3 neutrino generations.  $\Uparrow$  = large change  $\Uparrow$  = small change

		$\sin^2 2\theta_{13} > 0$	$\Delta m_{32}^2 (> 0, < 0)$	$\delta_{CP} = (\pi/4, -\pi/4)$	$\theta_{23} (< \pi/4, > \pi/4)$
$\nu$	0 – 1.2 GeV	$\Uparrow$	–, –	$\Uparrow, \Downarrow$	$\Uparrow, \Downarrow$
	1.2 – 2.2 GeV	$\Uparrow$	–, –	$\Uparrow, \Downarrow$	$\Downarrow, \Uparrow$
	> 2.2 GeV	$\Uparrow$	$\Uparrow, \Downarrow$	$\Uparrow, \Downarrow$	$\Downarrow, \Uparrow$
$\bar{\nu}$	0 – 1.2 GeV	$\Uparrow$	–, –	$\Downarrow, \Uparrow$	$\Uparrow, \Downarrow$
	1.2 – 2.2 GeV	$\Uparrow$	–, –	$\Downarrow, \Uparrow$	$\Downarrow, \Uparrow$
	> 2.2 GeV	$\Uparrow$	$\Downarrow, \Uparrow$	$\Downarrow, \Uparrow$	$\Downarrow, \Uparrow$

# Numerical calculation

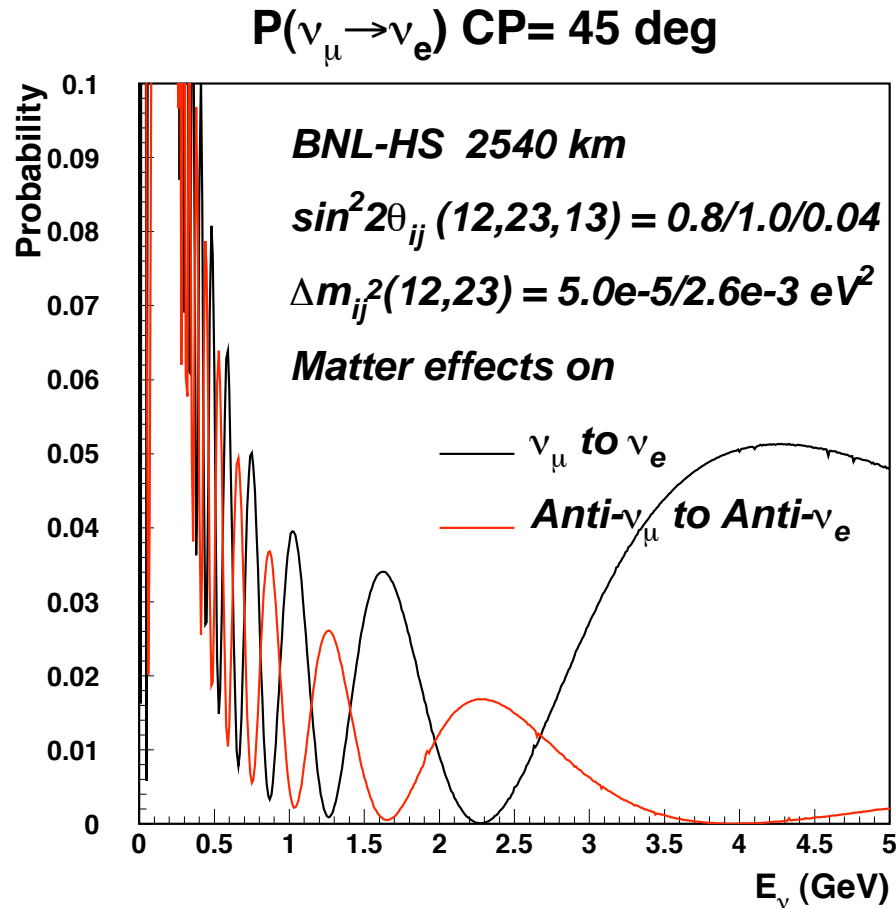


## General Features

- 0.5 – 1 GeV:  $\Delta m_{12}^2$  (LMA) region.
- 1 – 3 GeV: CP large effects region
- > 3 GeV: Matter enhanced ( $\nu_\mu$ ), suppressed ( $\bar{\nu}_\mu$ ). ( $\Delta m_{32}^2 > 0$ ) Region.

Exact numerical calculation

# Antineutrino



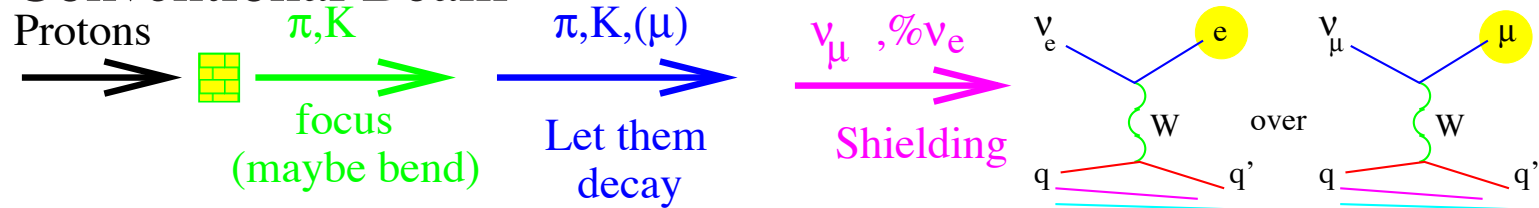
Compare Neutrino to Antineu.

- 0.5 – 1 GeV:  $\Delta m_{12}^2$  (LMA) region.
- 1 – 3 GeV: CP region
- > 3 GeV: Matter enhanced ( $\nu_\mu$ ), suppressed ( $\bar{\nu}_\mu$ ). ( $\Delta m_{32}^2 > 0$ ) Region.

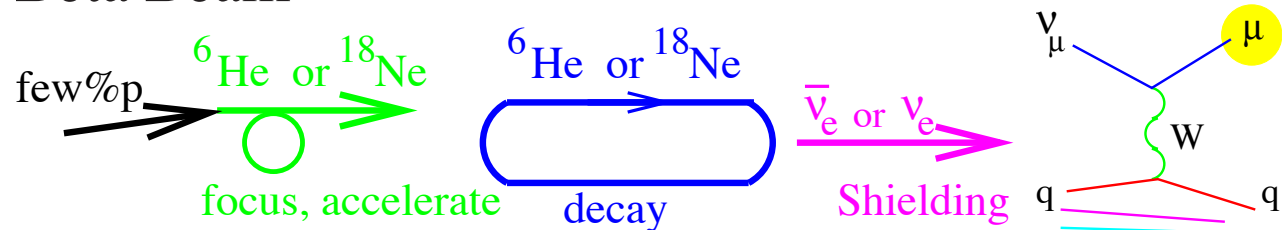
# Strategies for this physics

- Need pure intense beams (  $\nu_\mu$   $\nu_e$  )

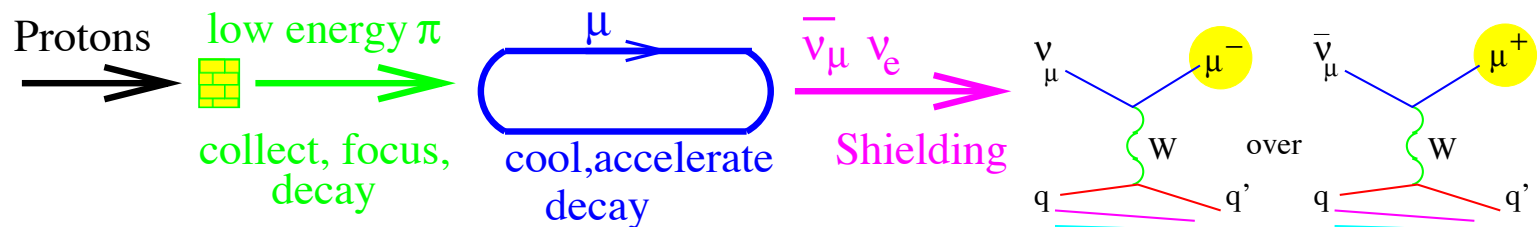
- Conventional Beam



- Beta Beam



- Neutrino Factory

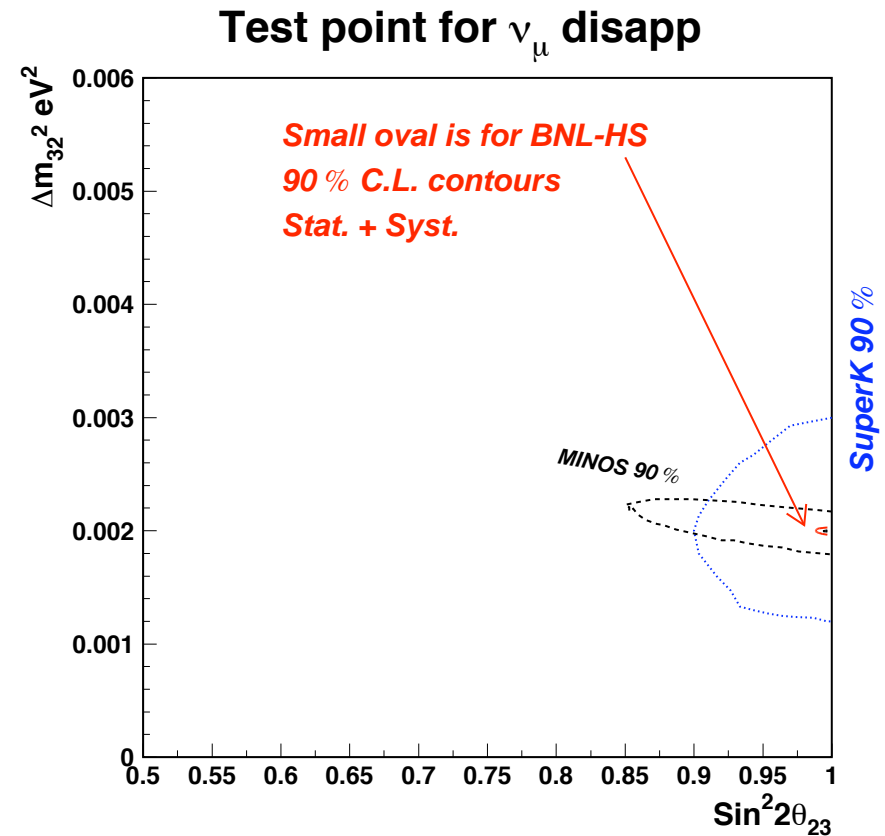
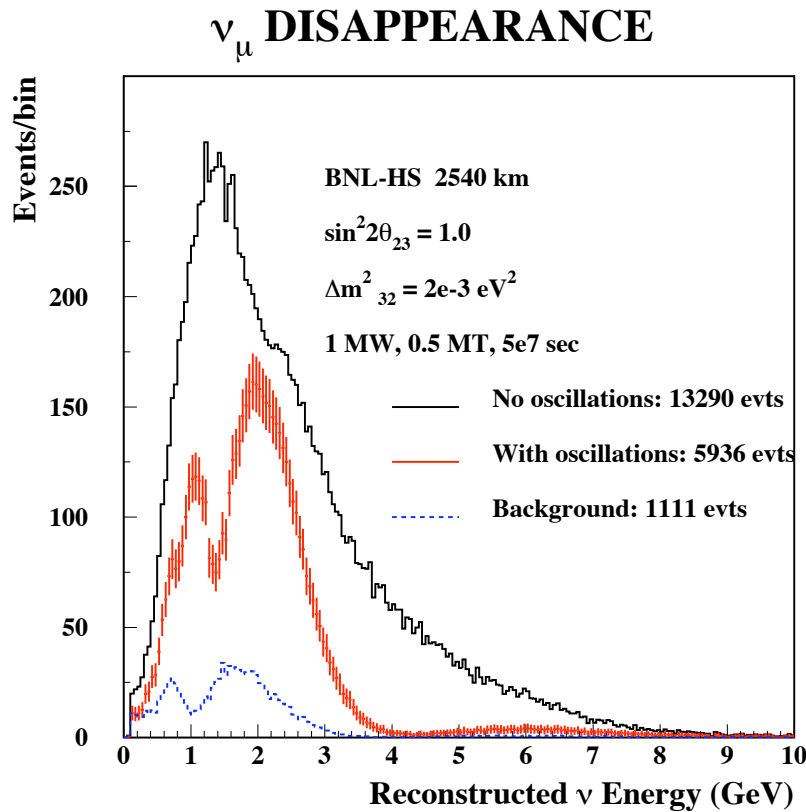


Focus on conventional beam for rest of the talk

# Conventional Beam Strategies

- Make narrow band beam using the Off-axis trick. Reduces backgrounds from Neutral current events. Perform experiment with at least two detectors at different  $L$ .
- Use wide band beam, use very large distance and a very large detector with good resolution to obtain spectrum. Need to demonstrate detector feasibility.

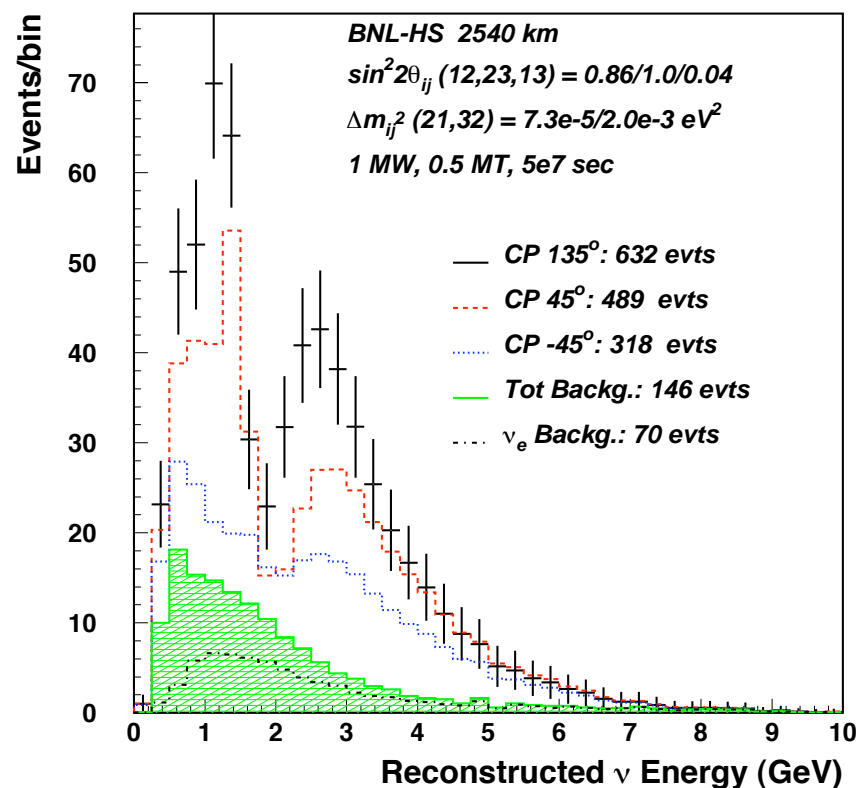
# Disappearance



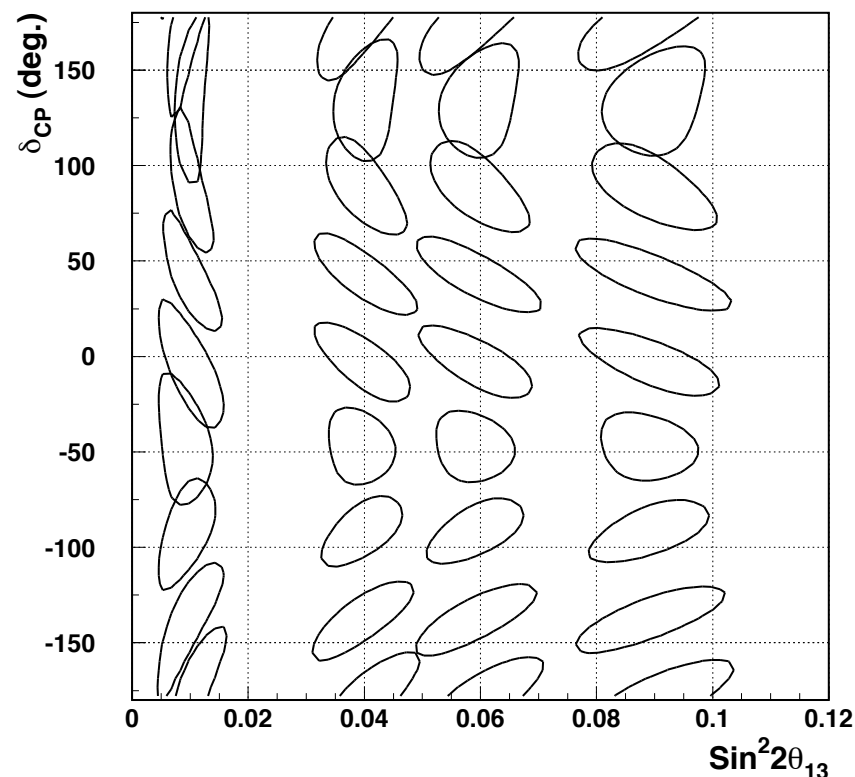
1% error on mixing and delta-m-squared

# Appearance

## $\nu_e$ APPEARANCE

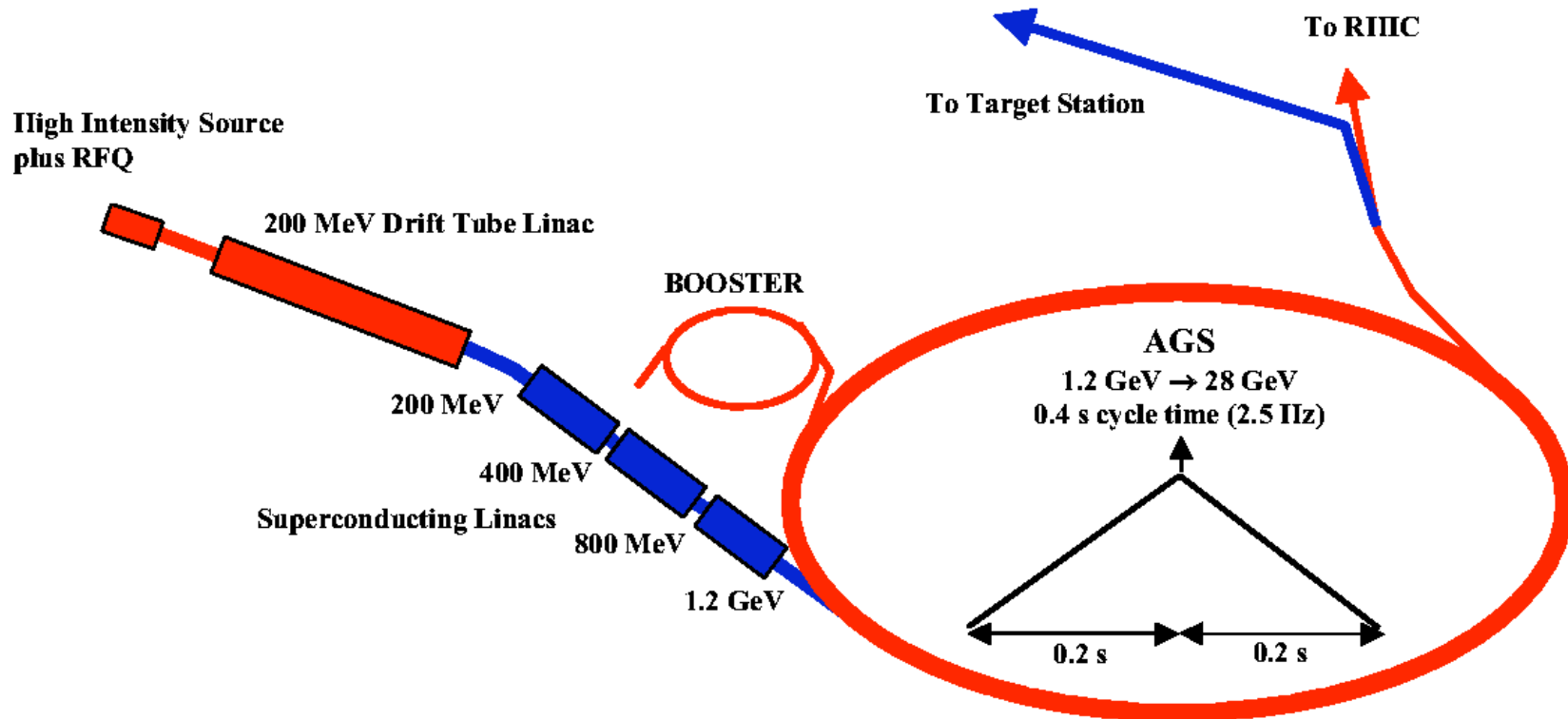


## Resolution $\delta_{CP}$ vs $\sin^2 2\theta_{13}$



one-sigma measurement

# BNL-AGS Target Power Upgrade to 1 MW

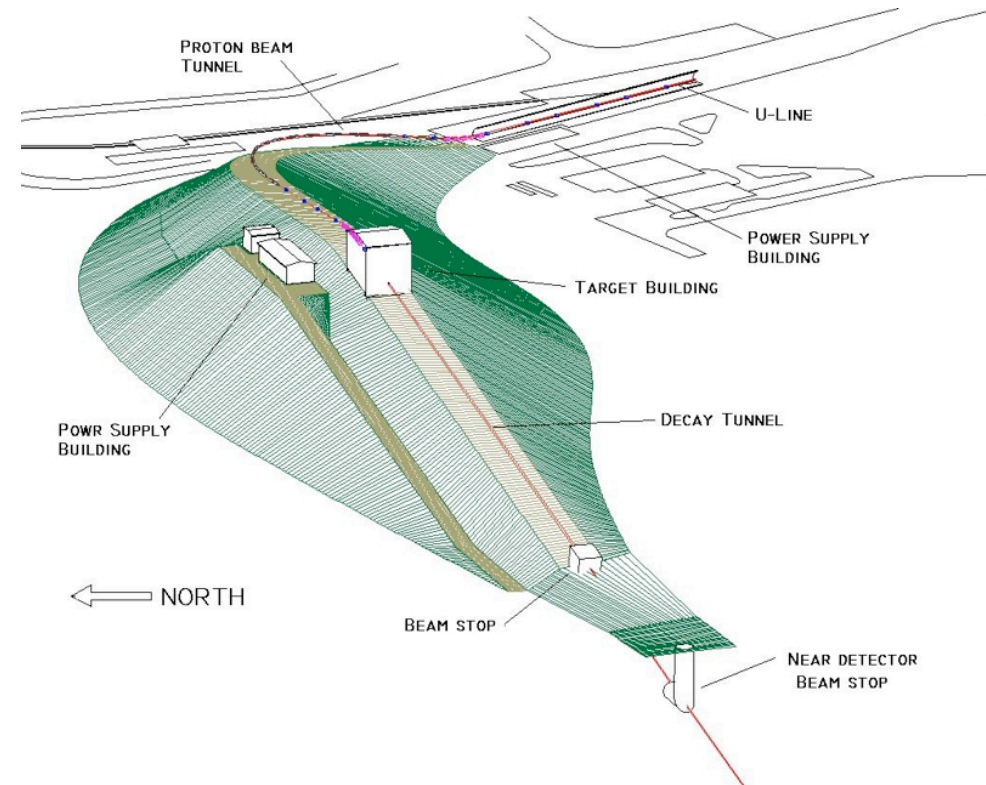
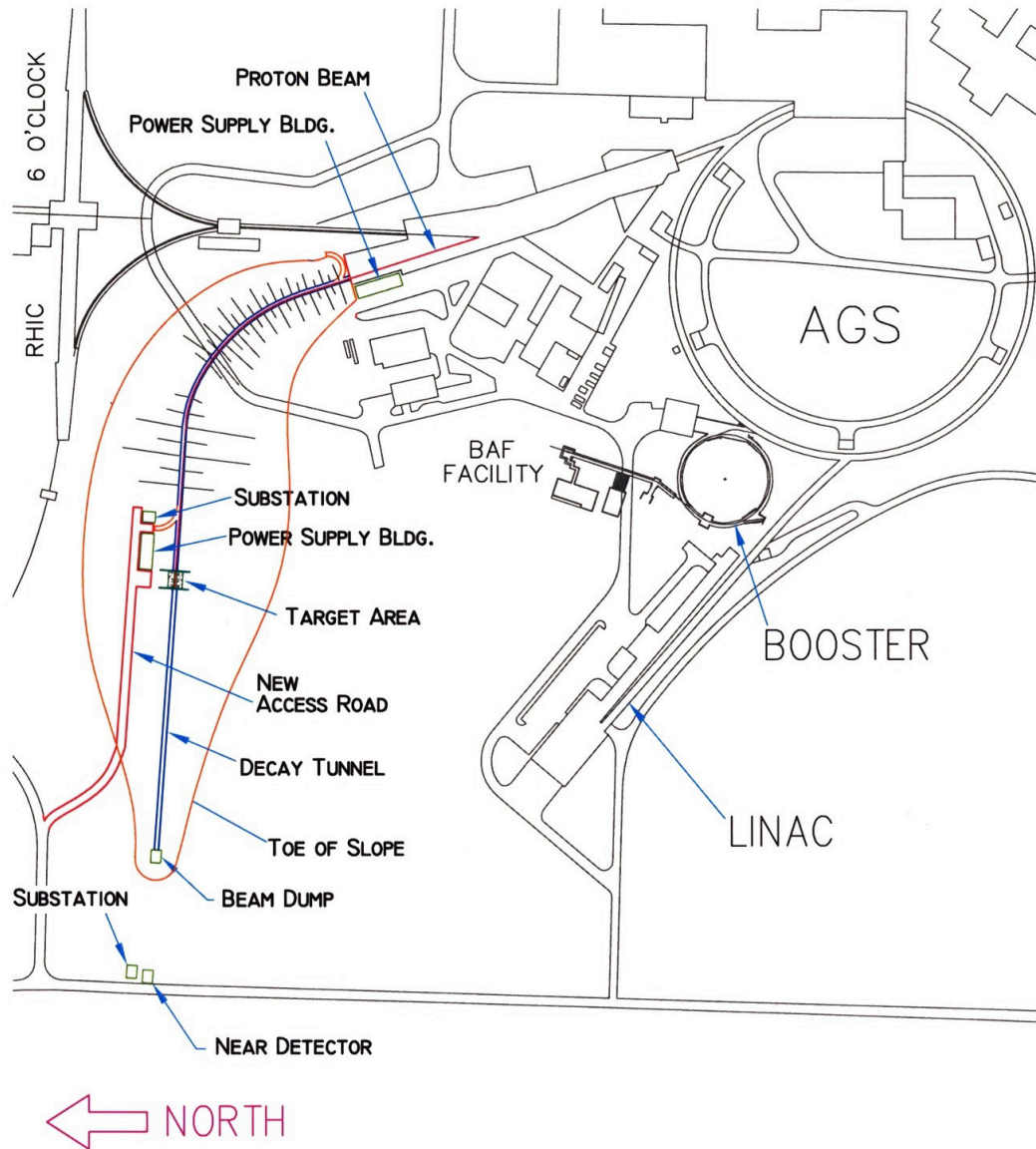


AGS is currently the highest intensity machine.  
Simple plan. Run the AGS faster. 2.5 Hz  
Need new LINAC @ 1.2 GeV to provide protons.

$$7 \times 10^{13} \text{ protons}/2 \text{ sec}$$

$$9 \times 10^{13} \text{ protons}/0.4 \text{ sec}$$

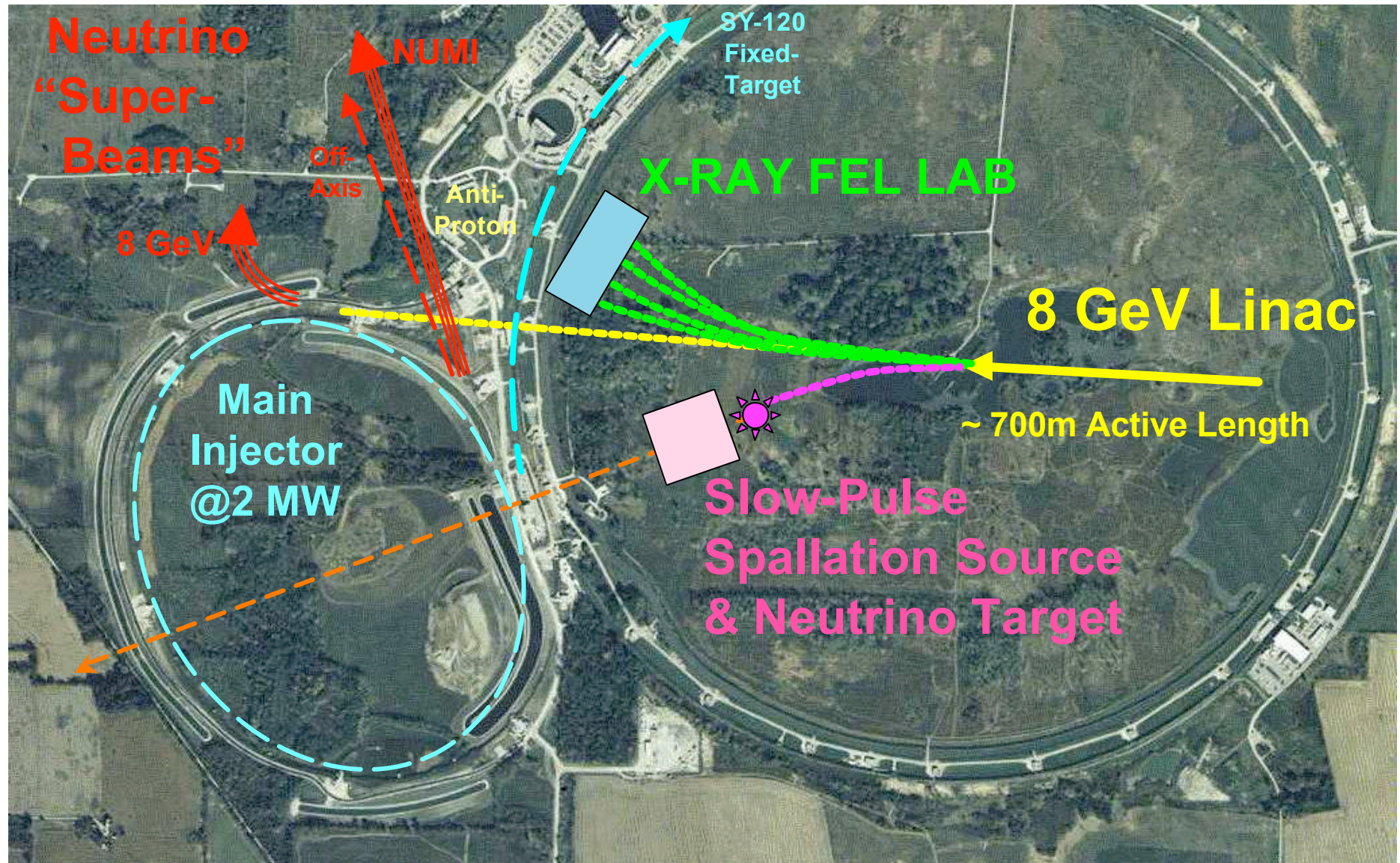
# 1 MW beam at BNL



- New design report next month
- target material cooling R&D in progress

# 8 GeV Superconducting Linac

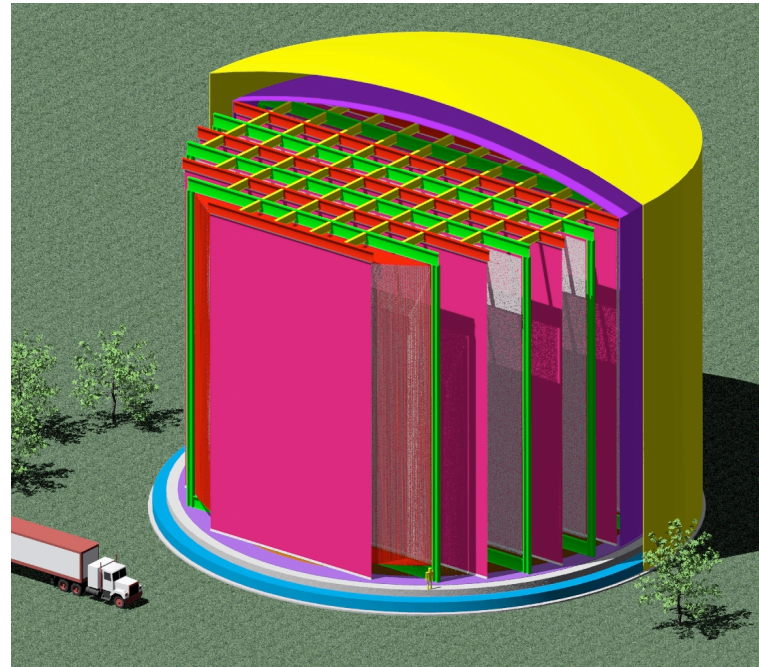
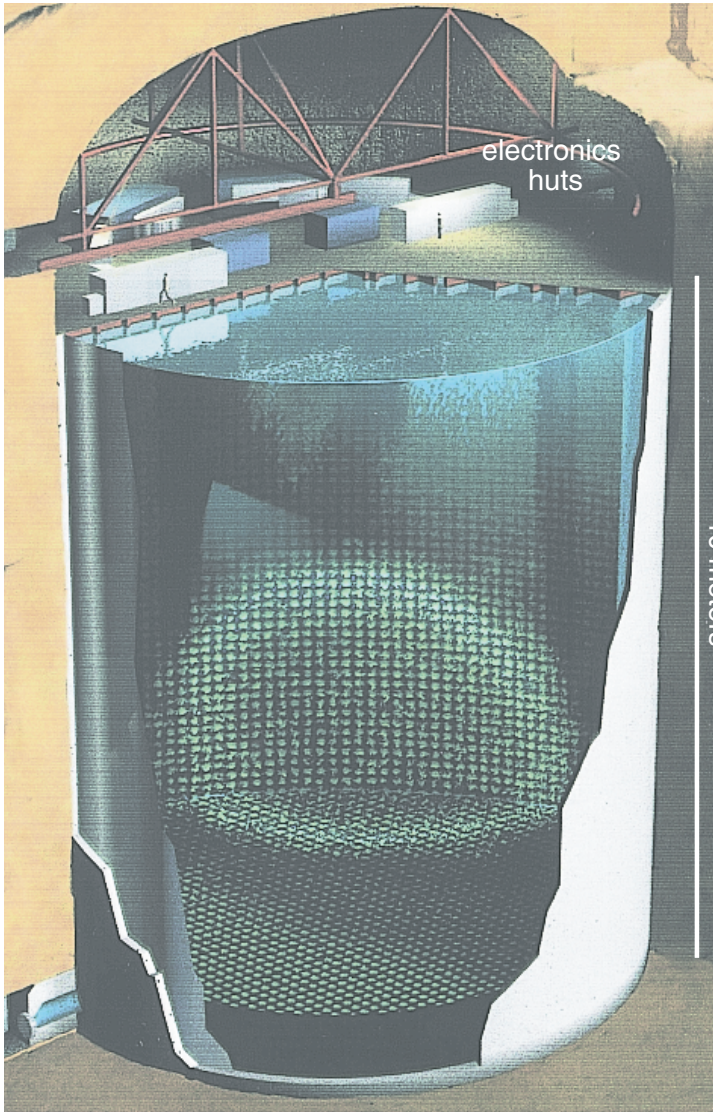
## With X-Ray FEL and 8 GeV Spallation & Neutrino Source



# Detector Requirements

- Fiducial Mass:
  - $> 500$  kT if using only “clean” events.  
Also needed for proton decay and neutrino astrophysics.
  - $\sim 100$  kT if fine grain and use all CC events.  
Selected proton decay modes still at the frontier.
- Threshold:  $\sim 10$  MeV, Dynamic range: contain 5 GeV  $\mu$
- Time res: few ns. Energy resolution:  $\sim 10$  %
- muon/electron discrimination:  $< 1$  %
- Pattern recognition:
  - 1, 2, 3 track separation
  - showering vs. multitrack separation.
  - need factor of 20-30 rejection capability around 1-2 GeV.
- Cost: 300 M\$ – 1000 M\$

# Detector Candidates and Issues.



- Water Cherenkov (500kT, ~100k 20" PMTs, Pattern Recognition, RICH?)
- Liquid Argon (100kT, ~250k Channels, Long wires, underground or above ?, Long drift distances.)
- Absorber+Scintillator (100kT, Readout, B-field, underground or above, pattern recognition.)

# Various efforts, comments

- Efforts underway: K2K(250) , MINOS(730) , T2K(295)
- NuMI offaxis. (700-900): existing beam, incremental approach. Good backg control, greater matter effect than T2K. 100kT on surface, need another detector at second max and intensity upgrade to get to CP. Detector is single purpose.
- Japarc-to-HyperK (295). Existing beam, 1 MT, offaxis beam, CP effect small, needs 4 MW upgrade.
- BNL-HS(2540): 500kT wide band beam, potential to overconstrain. Needs Detector R&D, pattern recognition needs solution. Could be done with off-axis run.
- FNAL-HS(1290): 500kT, probably similar performance to BNL-HS for CP, but less solar effect.

# Conclusion

- Much better understanding of the physics of leptonic mixing.
- Next big goal: leptonic CP
- Needs  $> 100\text{kT}$  detectors.
- Needs  $> 1\text{MW}$  proton accelerators.
- Opportunity for building new multipurpose facilities that can address many fundamental issues.
- Get involved in the NSF Solicitations !